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(54) Dielectric ceramic composition

(57) A dielectric ceramic composition mainly comprises a major component which comprises barium, titanium, neodymium, samarium and oxygen and is represented by the following compositional formula:



(wherein $0.1 \leq x \leq 0.2$; $0.5 \leq y \leq 0.8$; $0.01 \leq z \leq 0.2$; $0 \leq t \leq 0.2$, provided that $x+y+z+t=1$); and a minor component mainly comprising glass powder having a softening point of about 100 to about 500°C, which mainly comprises PbO, ZnO and B₂O₃, and GeO₂, and wherein the content (a) (% by weight) of the glass powder falls within the range of $1 \leq a \leq 25$ and the content (b) (% by weight) of GeO₂ falls within the range of $0.5 \leq b \leq 10$, on the basis of the weight of the major component. The major component may further comprise Bi₂O₃ and the composition may comprise bismuth as a minor component. The dielectric ceramic composition can be sintered at a low temperature and exhibits excellent characteristic properties such that it has a large specific dielectric constant ϵ_r , a large unloaded Q and a small temperature coefficient of the resonance frequency.

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Description

BACKGROUND OF THE INVENTION

5 Field of the Invention:

The present invention relates to a dielectric ceramic composition suitably used as a material for a dielectric resonator or the like.

10 Disclosure of the Prior Art:

There has recently been desired for the development of a small-sized and high performance dielectric resonator as integration of microwave circuits is increased. The dielectric ceramic composition used in such dielectric resonators must satisfy various requirements. For instance, the composition should have a large specific dielectric constant ϵ_r , a large unloaded Q and a low temperature coefficient of resonance frequency τ_f .

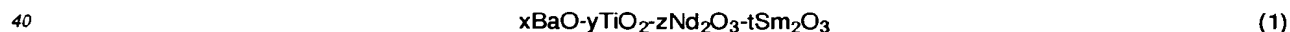
As examples of such dielectric ceramic compositions, Ber. Dt. Keram. Ges., 55 (1978), Nr. 7 and JPA No. Sho 60-35406 propose dielectric ceramic compositions comprising BaO-TiO₂-Nd₂O₃ systems. Moreover, U.S. Patent No. 5,292,694 discloses a dielectric ceramic composition comprising a BaO-TiO₂-RE₂O₃ system (wherein "RE" represents a rare earth metal). In addition, JPA No. Sho 62-72558 discloses a dielectric ceramic composition comprising a BaO-TiO₂-Nd₂O₃-Bi₂O₃ system.

There have recently been developed a laminated chip condenser and a laminated dielectric resonator, which are prepared by laminating a dielectric ceramic composition. In this respect, the ceramic composition and the internal electrode have been laminated by simultaneous firing. However, it is difficult to simultaneously firing the foregoing dielectric ceramic composition and the internal electrode, since the firing temperature of the former is high on the order of 1300 to 1400 °C and therefore, electrode materials for producing laminated structures are limited to those which are proof against a high temperature such as palladium (Pd) and platinum (Pt). For this reason, there has long been desired for the development of a dielectric ceramic composition capable of being fired simultaneously with cheaper electrode materials such as silver (Ag), silver-palladium (Ag-Pd) and copper (Cu), at a low temperature of not higher than 1200°C.

30 SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a dielectric ceramic composition which has excellent properties as a material for dielectric resonators or the like, in particular, a high dielectric constant, a high unloaded Q and low temperature-dependency of the resonance frequency and which exhibits good sinterability even if it is fired at a low temperature.

According to an aspect of the present invention, there is provided a dielectric ceramic composition which mainly comprises a major component comprising barium, titanium, neodymium, samarium and oxygen and represented by the following compositional formula:

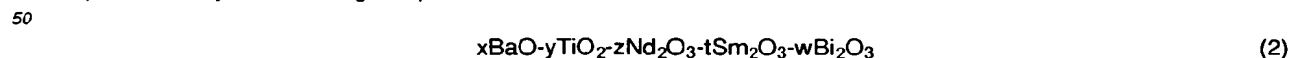


(wherein $0.1 \leq x \leq 0.2$; $0.5 \leq y \leq 0.8$; $0.01 \leq z \leq 0.2$; $0 \leq t \leq 0.2$, provided that $x+y+z+t = 1$); and

a minor component mainly comprising glass powder, which mainly comprises PbO, ZnO and B₂O₃, and GeO₂, and wherein

45 the content (a) (% by weight) of the glass powder falls within the range of $1 \leq a \leq 25$ and the content (b) (% by weight) of GeO₂ falls within the range of $0.5 \leq b \leq 10$, on the basis of the weight of the major component.

According to another aspect of the present invention, there is provided a dielectric ceramic composition mainly comprising a major component which comprises barium, titanium, neodymium, samarium, bismuth and oxygen and is represented by the following compositional formula:



(wherein $0.1 \leq x \leq 0.2$; $0.5 \leq y \leq 0.8$; $0.01 \leq z \leq 0.2$; $0.01 \leq t \leq 0.2$; $0.005 \leq w \leq 0.05$, provided that $x+y+z+t+w = 1$); and

55 a minor component mainly comprising glass powder, which mainly comprises PbO, ZnO and B₂O₃, and GeO₂, and wherein

the content (a) (% by weight) of the glass powder falls within the range of $1 \leq a \leq 25$ and the content (b) (% by weight) of GeO₂ falls within the range of $0.5 \leq b \leq 10$, on the basis of the weight of the major component.

The dielectric ceramic composition of the present invention may further comprise Li₂O as a minor component and the content (c) (% by weights of Li₂O falls within the range of $0.04 \leq c \leq 4$ on the basis of the weight of the major component.

The dielectric ceramic composition may also contain Nb_2O_5 , MnO , Al_2O_3 and/or ZnO .

In the ceramic composition of this invention, the content of PbO , ZnO and B_2O_3 in the glass powder are preferably in the range of $5 \leq \text{PbO} \leq 90$, $5 \leq \text{B}_2\text{O}_3 \leq 60$ and $0 < \text{ZnO} \leq 65$, more preferably $0 < \text{ZnO} \leq 50$ (% by weight).

If the softening point of the glass powder is higher than about 500°C , it becomes difficult to fire at a low temperature.

Although there is no limitation on the lower limit of the softening point of the glass powder, it is usually about 100°C .

It has been found that the dielectric ceramic composition of this invention has excellent characteristic properties such that it can be sintered at a low temperature and that it has a high dielectric constant, a large unloaded Q and low temperature-dependency of the resonance frequency.

The present invention is also provides a dielectric device such as a dielectric resonator and a dielectric filter, comprising the dielectric ceramic composition as above.

DETAILED DESCRIPTION OF THE INVENTION

First, the relative amounts of the oxides constituting the major component of the dielectric ceramic composition according to the present invention will be explained below. If the molar fraction of BaO exceeds the foregoing upper limit, the dielectric resonator produced from the resulting dielectric ceramic composition does not undergo any resonance. On the other hand, if it is less than the lower limit, the resulting dielectric resonator exhibits a low dielectric constant and a low unloaded Q.

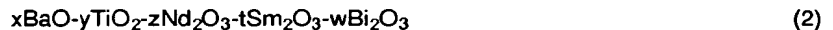
If the molar fraction of TiO_2 is greater than the upper limit defined above, the resulting dielectric resonator shows a large temperature coefficient of the resonance frequency, while if it is less than the lower limit, the dielectric constant of the resulting resonator is low. Moreover, if the molar fraction of Nd_2O_3 is greater than the upper limit defined above, the resulting dielectric resonator exhibits a low dielectric constant and a low unloaded Q, while if it is less than the lower limit, the temperature coefficient of the resonance frequency observed for the resulting dielectric resonator has a tendency to increase. In addition, the molar fraction of Sm_2O_3 has an effect on the dielectric constant, the unloaded Q and the temperature coefficient of the resonance frequency of the resulting dielectric resonator and therefore, a dielectric resonator exhibiting the desired characteristic properties can be produced only when it falls within the range defined above.

In the present invention, if the content of the minor component relative to the major component, i.e., the content (a) (% by weight) of the glass powder which mainly comprises PbO , ZnO and B_2O_3 and the content (b) (% by weight) of GeO_2 are extremely high, the unloaded Q of the resulting dielectric resonator is reduced, while these contents (a) and (b) are too low or zero, it becomes difficult to fire the resulting composition at a low temperature of not higher than 1200°C . For this reason, the content of the minor component relative to the major component, i.e., the content (a) (% by weight) of the glass powder which mainly comprises PbO , ZnO and B_2O_3 and the content (b) (% by weight) of GeO_2 are limited to the foregoing ranges, respectively. Moreover, the relative proportions of PbO , ZnO and B_2O_3 which constitute the glass powder are not particularly restricted, but if the content of ZnO is too high, the softening point of the resulting glass increases and it is difficult to fire the resulting composition at a low temperature. Accordingly, the content of ZnO in the glass powder is preferably $0 < \text{ZnO} \leq 65$, more preferably $0 < \text{ZnO} \leq 50$. The content of PbO and B_2O_3 falls preferably within $5 \leq \text{PbO} \leq 90$ and $5 \leq \text{B}_2\text{O}_3 \leq 60$ (% by weight), respectively.

And, if the softening point of the minor component, glass powder, is higher than about 500°C , it becomes difficult to fire at a low temperature.

The dielectric ceramic composition of the present invention may further comprise, as a minor component, Li_2O such that the content (c) (% by weight) thereof falls within the range of $0.04 \leq c \leq 4$. The addition of Li_2O permits a further decrease of the sintering temperature of the composition and as a result, an internal electrode of Ag can easily be formed. If the content (c) of Li_2O exceeds the upper limit defined above, the dielectric resonator produced from the resulting dielectric ceramic composition never undergoes resonance.

According to a second aspect of the present invention, there is further provided a dielectric ceramic composition which mainly comprises a major component comprising barium, titanium, neodymium, samarium, bismuth and oxygen and represented by the following compositional formula:



(wherein $0.1 \leq x \leq 0.2$; $0.5 \leq y \leq 0.8$; $0.01 \leq z \leq 0.2$; $0.01 \leq t \leq 0.2$; $0.005 \leq w \leq 0.05$, provided that $x+y+z+t+w = 1$); and

a minor component mainly comprising glass powder, which mainly comprises PbO , ZnO and B_2O_3 , and GeO_2 , and wherein

the content (a) (% by weight) of the glass powder falls within the range of $1 \leq a \leq 25$ and the content (b) (% by weight) of GeO_2 falls within the range of $0.5 \leq b \leq 10$, on the basis of the weight of the major component.

If the softening point of the minor component, glass powder is higher than about 500°C , it becomes difficult to fire at a low temperature.

In this composition, if the molar fraction of Bi_2O_3 is excessively high, the resulting composition exhibits a low dielectric constant and a low unloaded Q, while if it is extremely low, the dielectric resonator produced from the resulting composition has a high temperature coefficient of the resonance frequency. In the foregoing formula (2), the proportions of x, y, z and t as well as the contents (a) and (b) of the glass powder and GeO_2 as the minor component are limited to the foregoing ranges respectively, for the same reasons discussed above in connection with the foregoing formula (1).

This dielectric ceramic composition has excellent characteristic properties like the foregoing composition according to the first aspect such that it can also be sintered at a low temperature and that it has a high dielectric constant, a large unloaded Q and low temperature-dependency of the resonance frequency.

The dielectric ceramic composition according to the second aspect of the present invention may further comprise, as a minor component, Li_2O such that the content (c) (% by weight) thereof falls within the range of $0.04 \leq c \leq 4$. In this case, the addition of Li_2O likewise permits a further decrease of the sintering temperature of the composition and as a result, an internal electrode of Ag can easily be formed. If the content (c) of Li_2O exceeds the upper limit defined above, the dielectric resonator produced from the resulting dielectric ceramic composition never undergoes resonance.

In the present invention (the first and second aspects), at least one member selected from the group consisting of Nb_2O_5 , MnO , Al_2O_3 and ZnO may be added to the composition as the third component and this permits a further reduction in the absolute value of the temperature coefficient τ_f of the resonance frequency. If the content d (% by weight) of the third component on the basis of the major component is extremely high, the temperature coefficient τ_f of the resonance frequency increases. Therefore, the content (d) thereof falls within the range of $0 \leq d \leq 2$, preferably $0.1 \leq d \leq 2$.

Then a preferred method for preparing the dielectric ceramic composition of the present invention will be described below.

A starting material comprising various oxides constituting the major component, for instance, barium carbonate, titanium oxide, neodymium oxide, samarium oxide and, if necessary, bismuth oxide is subjected to wet blending in predetermined portions together with a solvent such as water or an alcohol. Subsequently, the solvent such as the water or the alcohol was removed, followed by pulverization of the mixture and then calcination thereof at a temperature ranging from 1000 to 1300 °C for about 1 to 5 hours in an oxygen-containing gas atmosphere (for instance, in the air). The calcined powder thus prepared is wet-blended with the minor component, i.e., the glass powder which is composed of PbO , ZnO and B_2O_3 and GeO_2 , and if necessary, Li_2O and the third component, i.e., at least one member selected from the group consisting of Nb_2O_5 , MnO , Al_2O_3 and ZnO in the presence of a solvent such as an alcohol. Then the solvent such as the water or the alcohol is removed and thereafter the mixture is pulverized. Moreover, the product is uniformly mixed with an organic binder such as polyvinyl alcohol, followed by drying, pulverization and pressure molding (under a pressure ranging from about 100 to 1000 kg/cm^2). Thereafter, a dielectric ceramic composition represented by the foregoing compositional formula (1) or (2) can be obtained by firing the resulting molded article at a temperature ranging from 850 to 1100 °C in an oxygen-containing gas atmosphere, for instance, in the air.

The dielectric ceramic composition thus prepared may be, according to need, processed into appropriate shapes and sizes, or formed into a sheet by, for instance, the doctor blade technique followed by lamination of the sheet with an electrode and may thus be used as a material for a dielectric resonator, a dielectric substrate, a laminated element or the like.

As raw materials for barium, titanium, neodymium, samarium, niobium, bismuth, lead, zinc, boron, germanium, manganese, aluminum and lithium, there may be used, for instance, nitrates and hydroxides thereof which are converted into oxides during the firing process in addition to oxides thereof such as BaCO_3 , TiO_2 , Nd_2O_3 , Sm_2O_3 , Bi_2O_3 , PbO , ZnO , B_2O_3 , GeO_2 , Nb_2O_5 , MnO , Al_2O_3 and Li_2O .

The present invention will hereinafter be described in more detail with reference to the following non-limitative working Examples and Comparative Examples.

Example 1

Barium carbonate powder (BaCO_3 ; 0.13 mole), titanium oxide powder (TiO_2 ; 0.70 mole) and neodymium oxide powder (Nd_2O_3 ; 0.17 mole) were charged in a ball mill together with ethanol and then subjected to wet blending for 12 hours. After the removal of the solvent from the dispersion, the mixture was pulverized and then calcined at 1250 °C in the air. Separately, glass powder A comprising 84wt% of lead oxide powder (PbO), 7 wt% of zinc oxide powder (ZnO) and 9 wt% of boron oxide powder (B_2O_3) was prepared according to the usual method. To the calcined product prepared above, there were added 2 wt% of the glass powder A comprising PbO , ZnO and B_2O_3 , and 3 wt% of germanium oxide powder (GeO_2), followed by introduction of the mixture into a ball mill together with ethanol and then wet blending for 48 hours. After the removal of the solvent from the dispersion, the mixture was pulverized, followed by addition of an appropriate amount of a polyvinyl alcohol solution to the pulverized product, drying the mixture, forming it into pellets having a diameter of 12 mm and a thickness of 4 mm and then firing the pellets at 970°C for 2 hours in the air. The composition of the product and the sintering temperature thereof are summarized in the following Table 1.

The ceramic composition thus prepared was processed into pieces each having a diameter of 7 mm and a thickness of about 3 mm and inspected for the specific dielectric constant ϵ_r , the unloaded Q and the temperature coefficient τ_f of

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the resonance frequency at a resonance frequency (ranging from 3 to 6 GHz) according to the dielectric resonance method. The results thus obtained are listed in the following Table 2.

Examples 2 to 22 and Comparative Examples 1 to 12

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The same procedures used in Example 1 were repeated except that the mixing ratio of barium carbonate, titanium oxide, neodymium oxide and samarium oxide; the kinds of glass powder comprising PbO, ZnO and B₂O₃ (glass powder B: 80 wt% PbO, 10 wt% ZnO and 10 wt% B₂O₃) and the added amounts of the minor components as well as the added amount (d) of the third component were changed as detailed in Table 1 to prepare dielectric ceramic compositions and they were inspected for characteristic properties. The compositions of the products prepared in these Examples and

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Comparative Examples and characteristic properties thereof are summarized in Table 2.

TABLE 1

5		COMPOSITION OF DIELECTRIC CERAMIC							CALCINATION	
		BaO	TiO ₂	Nd ₂ O ₃	Sm ₂ O ₃	GLASS	KIND OF	GeO ₂	d	TEMPERATURE
		x	y	z	t	POWDER	GLASS	wt%	wt%	°C
					wt%					
10	EXAMPLE									
	1	0.13	0.70	0.17	0	2	A	3	-	970
	2	0.18	0.67	0.11	0.04	7	A	3	-	940
	3	0.18	0.67	0.11	0.04	10	A	3	-	915
	4	0.18	0.67	0.11	0.04	15	A	3	-	890
15	5	0.16	0.67	0.11	0.06	20	A	2	-	880
	6	0.18	0.66	0.13	0.03	5	B	5	-	990
	7	0.17	0.67	0.10	0.06	10	B	3	-	960
	8	0.16	0.65	0.17	0.02	15	B	3	-	940
20	9	0.13	0.70	0.17	0	7	A	3	-	950
	10	0.13	0.70	0.15	0.02	7	A	3	-	945
	11	0.13	0.70	0.12	0.05	7	A	3	-	950
	12	0.14	0.71	0.04	0.11	10	A	5	-	935
25	13	0.17	0.66	0.17	0	10	A	5	-	925
	14	0.17	0.66	0.17	0	10	A	7	-	915
	15	0.17	0.66	0.17	0	10	A	10	-	935
	16	0.16	0.65	0.18	0.01	7	A	3	-	940
	17	0.15	0.67	0.18	0	10	A	5	-	905
30	18	0.15	0.67	0.18	0	15	A	3	-	875
	19	0.15	0.67	0.18	0	12	A	5	0.5(Nb ₂ O ₅)	910
	20	0.15	0.67	0.18	0	12	A	5	0.5(MnO)	915
	21	0.15	0.67	0.18	0	12	A	5	0.5(Al ₂ O ₃)	920
35	22	0.15	0.67	0.18	0	12	A	5	0.5(ZnO)	910
COMPARATIVE										
EXAMPLE										
40	1	0.05	0.75	0.19	0.01	10	A	5	-	960
	2	0.30	0.57	0.11	0.02	10	A	3	-	935
	3	0.08	0.86	0.05	0.01	15	A	3	-	920
	4	0.15	0.45	0.39	0.01	9	A	2	-	930
	5	0.11	0.57	0.31	0.01	10	A	2	-	920
45	6	0.10	0.89	0	0.01	10	A	2	-	925
	7	0.14	0.55	0.01	0.30	5	A	3	-	945
	8	0.15	0.70	0.13	0.02	0	-	0	-	1420
	9	0.16	0.67	0.11	0.06	30	A	2	-	870
	10	0.16	0.65	0.17	0.02	30	B	3	-	860
50	11	0.17	0.66	0.17	0	20	A	0	-	1160
	12	0.15	0.70	0.13	0.02	10	A	15	-	890

TABLE 2

ELECTRIC CHARACTERISTICS

EXAMPLE	ϵ_r	Q	τ_r ppm/°C
1	71.0	1510	13
2	76.0	1190	6
3	70.0	1120	-5
4	68.0	910	-8
5	65.0	660	-22
6	74.0	1080	12
7	70.0	750	-7
8	67.0	615	-5
9	69.0	1305	8
10	69.5	1180	-7
11	68.0	975	21
12	61.0	715	-2
13	68.0	1060	18
14	64.0	1020	14
15	58.0	910	8
16	71.0	1120	16
17	62.0	1070	-46
18	66.0	720	-49
19	61.0	1100	-30
20	63.0	1120	-25
21	62.0	1090	-32
22	61.0	1110	-21

COMPARATIVE
EXAMPLE

1	44.0	150	-1
2	NO RESONANCE		
3	64.0	305	140
4	35.0	205	45
5	43.0	80	-6
6	60.0	1510	86
7	41.0	260	-31
8	87.0	2870	18
9	27.0	195	-7
10	23.0	145	7
11	94.0	80	81
12	41.0	220	-43

Example 23

Barium carbonate powder (BaCO_3 ; 0.13 mole), titanium oxide powder (TiO_2 ; 0.70 mole) and neodymium oxide powder (Nd_2O_3 ; 0.17 mole) were charged in a ball mill together with ethanol and then subjected to wet blending for 12 hours. After the removal of the solvent from the dispersion, the mixture was pulverized and then calcined at 1250 °C in the air. Separately, glass powder A comprising 84wt% of lead oxide powder (PbO), 7 wt% of zinc oxide powder (ZnO) and 9 wt% of boron oxide powder (B_2O_3) was prepared according to the usual method. To the calcined product prepared above, there were added 2 wt% of the glass powder A comprising PbO , ZnO and B_2O_3 as well as 3 wt% of germanium oxide powder (GeO_2) and 1 wt% (corresponding to 0.4 wt% as expressed in terms of the amount of Li_2O) of lithium carbonate powder (Li_2CO_3), followed by introduction of the mixture into a ball mill together with ethanol and then wet blending for 48 hours. After the removal of the solvent from the dispersion, the mixture was pulverized, followed by addition of an appropriate amount of a polyvinyl alcohol solution to the pulverized product, drying the mixture, forming it into pellets having a diameter of 12 mm and a thickness of 4 mm and then firing the pellets at 955°C for 2 hours in the air. The composition of the product and the sintering temperature thereof are summarized in the following Table 3.

The ceramic composition thus prepared was inspected for various characteristic properties which were determined under the same conditions used in Example 1. The results thus obtained are listed in the following Table 5.

Examples 24 to 47 and Comparative Examples 13 to 28

The same procedures used in Example 23 were repeated except that the mixing ratio of barium carbonate, titanium oxide, neodymium oxide and samarium oxide; the kinds of glass powder as a minor component mainly comprising PbO , ZnO and B_2O_3 in the ratio listed in Table 4 and the added amounts of the minor components were changed as detailed in Table 3 to prepare dielectric ceramic compositions and they were inspected for characteristic properties. The results

thus obtained are summarized in Table 5.

TABLE 3
COMPOSITION OF DIELECTRIC CERAMIC

		BaO	TiO ₂	Nd ₂ O ₃	Sm ₂ O ₃	GLASS POWDER wt%	KIND OF GLASS	GeO ₂ wt%	Li ₂ O wt%	CALCINATION TEMPERATURE °C
		x	y	z	t					
5	EXAMPLE									
	23	0.13	0.70	0.17	0	2	A	3	0.4	955
10	24	0.18	0.67	0.11	0.04	7	A	3	0.2	930
	25	0.18	0.67	0.11	0.04	10	A	3	0.2	900
	26	0.18	0.67	0.11	0.04	15	A	3	0.2	885
	27	0.16	0.67	0.11	0.06	20	A	2	0.4	855
	28	0.18	0.66	0.13	0.03	5	B	5	0.4	970
15	29	0.17	0.67	0.10	0.06	10	B	3	0.8	940
	30	0.16	0.65	0.17	0.02	15	B	3	0.4	910
	31	0.13	0.70	0.17	0	7	A	3	0.4	930
	32	0.13	0.70	0.15	0.02	7	A	3	0.4	925
20	33	0.13	0.70	0.12	0.05	7	A	3	0.4	925
	34	0.14	0.71	0.04	0.11	10	A	5	0.2	930
	35	0.17	0.66	0.17	0	10	A	5	0.2	915
	36	0.17	0.66	0.17	0	10	A	7	0.2	910
	37	0.17	0.66	0.17	0	10	A	10	0.2	930
25	38	0.16	0.65	0.18	0.01	7	A	3	0.2	935
	39	0.16	0.65	0.18	0.01	7	A	3	0.4	915
	40	0.16	0.65	0.18	0.01	7	A	3	0.6	905
	41	0.16	0.65	0.18	0.01	7	A	3	0.8	885
	42	0.15	0.67	0.18	0	10	A	5	0.4	880
30	43	0.15	0.67	0.18	0	15	A	3	0.4	850
	44	0.17	0.66	0.17	0	20	C	-	-	950
	45	0.16	0.67	0.17	0	18	D	-	-	940
	46	0.16	0.67	0.17	0	20	E	-	-	940
	47	0.16	0.66	0.18	0	17	F	5	0.3	850
35	COMPARATIVE EXAMPLE									
	13	0.05	0.75	0.19	0.01	10	A	5	0.2	945
	14	0.30	0.57	0.11	0.02	10	A	3	0.2	930
40	15	0.08	0.86	0.05	0.01	15	A	3	0.4	890
	16	0.15	0.45	0.39	0.01	9	A	2	0.6	900
	17	0.11	0.57	0.31	0.01	10	A	2	0.8	890
	18	0.10	0.89	0	0.01	10	A	2	0.4	910
	19	0.14	0.55	0.01	0.30	5	A	3	0.4	920
45	20	0.15	0.70	0.13	0.02	0	-	0	0	1420
	21	0.16	0.67	0.11	0.06	30	A	2	0.4	840
	22	0.16	0.65	0.17	0.02	30	B	3	0.4	835
	23	0.17	0.66	0.17	0	20	A	0	0.2	1150
50	24	0.15	0.70	0.13	0.02	10	A	15	0.4	840
	25	0.16	0.65	0.18	0.01	7	A	3	6.0	860
	26	0.17	0.67	0.10	0.06	10	B	3	0	960
	27	0.17	0.66	0.17	0	20	G	-	-	900
	28	0.15	0.70	0.13	0.02	19	H	-	-	900
55										

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TABLE 4

KIND OF GLASS	GLASS POWDER COMPOSITION (wt%)						SOFTENING POINT (°C)
A	PbO (84)	ZnO (7)	B ₂ O ₃ (9)				315
B	PbO (80)	ZnO (10)	B ₂ O ₃ (10)				310
C	PbO (52)	ZnO (4)	B ₂ O ₃ (6)	GeO ₂ (31)	Li ₂ O (7)		417
D	PbO (56)	ZnO (5)	B ₂ O ₃ (6)	GeO ₂ (33)			480
E	PbO (51)	ZnO (4)	B ₂ O ₃ (5)	GeO ₂ (30)	Li ₂ O (6)	Sb ₂ O ₃ (4)	442
F	PbO (74)	PbF ₂ (10)	B ₂ O ₃ (9)	ZnO (7)			275
G	B ₂ O ₃ (35)	SiO ₂ (45)	Al ₂ O ₃ (10)	BaO (10)			650
H	B ₂ O ₃ (24)	SiO ₂ (35)	BaO (41)				690

TABLE 5

ELECTRIC CHARACTERISTICS

EXAMPLE	ϵ_r	Q	τ_r ppm/°C
23	75.0	1590	37
24	77.0	1260	21
25	72.0	1110	10
26	70.5	925	6
27	69.0	660	4
28	78.0	1105	37
29	72.0	790	32
30	71.0	620	23
31	74.0	1310	31
32	73.5	1250	17
33	72.0	1000	-3
34	63.0	720	-16
35	70.0	1090	32
36	66.0	1100	27
37	61.0	980	21
38	73.0	1180	33
39	75.0	1120	42
40	78.0	1090	47
41	74.0	820	54
42	66.0	1150	-19
43	69.0	780	-20
44	60.0	850	5
45	61.5	920	-12
46	61.0	1000	16
47	68.0	1250	-8

COMPARATIVE

EXAMPLE

13	47.0	160	14
14	NO RESONANCE		
15	68.0	310	166
16	41.0	210	76
17	45.0	100	36
18	65.0	320	110
19	44.0	280	-2
20	87.0	2870	18
21	31.0	210	19
22	26.0	160	31
23	96.0	100	85
24	43.0	250	-19
25	NO RESONANCE		
26	70.0	750	-7
27	NO SINTERING		
28	NO SINTERING		

Example 48

Barium carbonate powder (BaCO_3 ; 0.15 mole), titanium oxide powder (TiO_2 ; 0.675 mole), neodymium oxide powder (Nd_2O_3 ; 0.13 mole), samarium oxide powder (Sm_2O_3 ; 0.02 mole) and bismuth oxide powder (Bi_2O_3 ; 0.025 mole) were charged in a ball mill together with ethanol and then subjected to wet blending for 12 hours. After the removal of the solvent from the dispersion, the mixture was pulverized and then calcined at 1100°C in the air. Separately, glass powder A comprising 84wt% of lead oxide powder (PbO), 7 wt% of zinc oxide powder (ZnO) and 9 wt% of boron oxide powder (B_2O_3) was prepared according to the usual method. To the calcined product prepared above, there were added 2 wt% of the glass powder A comprising PbO , ZnO and B_2O_3 , and 2 wt% of germanium oxide powder (GeO_2), followed by introducing the mixture into a ball mill together with ethanol and then wet blending for 12 hours. After the removal of the solvent from the dispersion, the mixture was pulverized, followed by addition of an appropriate amount of a polyvinyl alcohol solution to the pulverized product, drying the mixture, forming it into pellets having a diameter of 12 mm and a thickness of 4 mm and then firing the pellets at 1150°C for 2 hours in the air. The composition of the product and the sintering temperature thereof are summarized in the following Table 6.

The ceramic composition thus prepared was inspected for various characteristic properties which were determined under the same conditions used in Example 23. The results thus obtained are listed in the following Table 6.

The ceramic composition thus prepared was processed into pieces each having a diameter of 7 mm and a thickness of about 3 mm and inspected for the specific dielectric constant ϵ_r , the unloaded Q and the temperature coefficient τ_f of the resonance frequency at a resonance frequency (ranging from 3 to 5 GHz) according to the dielectric resonance method. The results thus obtained are listed in the following Table 7.

Examples 49 to 61 and Comparative Examples 29 to 47

The same procedures used in Example 48 were repeated except that the mixing ratio of barium carbonate, titanium oxide, neodymium oxide, samarium oxide and bismuth oxide; the kinds and the added amount of glass powder comprising PbO , ZnO and B_2O_3 (glass powder B: 80 wt% PbO , 10 wt% ZnO and 10 wt% B_2O_3) and the added amounts of the minor component GeO_2 as well as the added amount (d) of the third component were changed as detailed in Table 6 to prepare dielectric ceramic compositions and they were inspected for characteristic properties in the same manner

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used in Example 48. The results thus obtained are summarized in Table 7.

TABLE 6

5		COMPOSITION OF DIELECTRIC CERAMIC								CALCINATION	
		BaO x	TiO ₂ y	Nd ₂ O ₃ z	Sm ₂ O ₃ t	Bi ₂ O ₃ w	GLASS POWDER wt%	KIND OF GLASS	GeO ₂ wt%	d wt%	TEMPERATURE °C
10	EXAMPLE										
	48	0.15	0.675	0.13	0.02	0.025	2	A	2	-	1050
	49	0.12	0.675	0.13	0.05	0.025	7	A	2	-	950
	50	0.17	0.695	0.10	0.01	0.025	10	A	2	-	930
	51	0.15	0.675	0.13	0.02	0.025	15	A	2	-	920
15	52	0.15	0.675	0.13	0.02	0.025	20	A	2	-	910
	53	0.15	0.675	0.13	0.02	0.025	10	A	3	-	930
	54	0.15	0.675	0.13	0.02	0.025	10	A	2	1(Nb ₂ O ₅)	910
	55	0.15	0.675	0.13	0.02	0.025	10	A	2	1(MnO)	920
	56	0.15	0.675	0.13	0.02	0.025	10	A	2	1(Al ₂ O ₃)	930
20	57	0.15	0.675	0.13	0.02	0.025	10	A	2	1(ZnO)	930
	58	0.15	0.675	0.13	0.02	0.025	3	B	3	-	1050
	59	0.12	0.675	0.13	0.05	0.025	8	B	2	-	950
	60	0.17	0.695	0.10	0.01	0.025	11	B	2	-	940
25	61	0.15	0.675	0.13	0.02	0.025	15	B	5	-	920
COMPARATIVE											
EXAMPLE											
	29	0.05	0.75	0.18	0.01	0.01	10	A	5	-	960
30	30	0.30	0.57	0.10	0.02	0.01	8	A	2	-	920
	31	0.08	0.85	0.05	0.01	0.01	15	A	3	-	900
	32	0.15	0.45	0.37	0.01	0.02	9	A	2	-	920
	33	0.11	0.57	0.30	0.01	0.01	10	A	2	-	930
	34	0.15	0.81	0	0.01	0.03	10	A	2	-	920
35	35	0.15	0.675	0.15	0	0.025	8	A	2	-	910
	36	0.12	0.545	0.01	0.30	0.025	5	A	2	-	990
	37	0.15	0.675	0.155	0.02	0	8	A	3	-	1030
	38	0.15	0.60	0.13	0.02	0.10	5	A	2	-	990
	39	0.15	0.675	0.13	0.02	0.025	0	-	0	-	1350
40	40	0.15	0.675	0.13	0.02	0.025	30	A	2	-	870
	41	0.15	0.675	0.13	0.02	0.025	30	B	2	-	890
	42	0.15	0.675	0.13	0.02	0.025	8	A	0.1	-	1250
	43	0.15	0.675	0.13	0.02	0.025	8	A	15	-	850
45	44	0.15	0.675	0.13	0.02	0.025	10	A	2	5(Nb ₂ O ₅)	940
	45	0.15	0.675	0.13	0.02	0.025	10	A	2	5(MnO)	900
	46	0.15	0.675	0.13	0.02	0.025	10	A	2	5(Al ₂ O ₃)	900
	47	0.15	0.675	0.13	0.02	0.025	10	A	2	5(ZnO)	900

50

55

TABLE 7

ELECTRIC CHARACTERISTICS

	ϵ_r	Q	τ_r ppm/°C
EXAMPLE			
48	81.0	1150	7
49	74.0	930	-22
50	77.0	800	-12
51	77.0	1100	-13
52	78.0	950	-30
53	77.0	450	-14
54	76.0	820	-3
55	77.0	560	4
56	74.0	620	2
57	78.0	750	-8
58	80.0	1050	7
59	73.0	890	-21
60	74.0	720	-11
61	73.0	630	-17

COMPARATIVE

EXAMPLE

29	51.0	120	-12
30	NO RESONANCE		
31	70.0	400	130
32	41.0	170	33
33	49.0	80	-15
34	43.0	130	-35
35	80.0	130	-26
36	46.0	240	-38
37	79.0	1050	33
38	41.0	200	33
39	93.0	1200	5
40	33.0	180	-7
41	29.0	150	-5
42	85.0	1100	-33
43	45.0	200	-55
44	74.0	210	25
45	77.0	250	33
46	72.0	220	27
47	71.0	240	22

Example 62

Barium carbonate powder (BaCO_3 ; 0.13 mole), titanium oxide powder (TiO_2 ; 0.69 mole), neodymium oxide powder (Nd_2O_3 ; 0.16 mole) and bismuth oxide powder (Bi_2O_3 ; 0.02 mole) were charged in a ball mill together with ethanol and

then subjected to wet blending for 12 hours. After the removal of the solvent from the dispersion, the mixture was pulverized and then calcined at 1250°C in the air. Separately, glass powder A comprising 84wt% of lead oxide powder (PbO), 7 wt% of zinc oxide powder (ZnO) and 9 wt% of boron oxide powder (B₂O₃) was prepared according to the usual method. To the calcined product prepared above, there were added 2 wt% of the glass powder A comprising PbO, ZnO and B₂O₃, 3 wt% of germanium oxide powder (GeO₂) and 1 wt% (corresponding to 0.4 wt% as expressed in terms of the weight of Li₂O) of lithium carbonate powder (Li₂CO₃), followed by introduction of the mixture into a ball mill together with ethanol and then wet blending for 48 hours. After the removal of the solvent from the dispersion, the mixture was pulverized, followed by addition of an appropriate amount of a polyvinyl alcohol solution to the pulverized product, drying the mixture, forming it into pellets having a diameter of 12 mm and a thickness of 4 mm and then firing the pellets at 945°C for 2 hours in the air. The composition of the product and the sintering temperature thereof are summarized in the following Table 8.

The ceramic composition thus prepared was processed into pieces each having a diameter of 7 mm and a thickness of about 3 mm and inspected for the specific dielectric constant ϵ_r , the unloaded Q and the temperature coefficient τ_f of the resonance frequency at a resonance frequency (ranging from 3 to 6 GHz) according to the dielectric resonance method. The results thus obtained are listed in the following Table 9.

Examples 63 to 82 and Comparative Examples 48 to 62

The same procedures used in Example 62 were repeated except that the mixing ratio of barium carbonate, titanium oxide, neodymium oxide, samarium oxide and bismuth oxide; the kinds of glass powder comprising PbO, ZnO and B₂O₃ (glass powder B: 80 wt% PbO, 10 wt% ZnO and 10 wt% B₂O₃) and the added amounts of the minor components were changed as detailed in Table 8 to prepare dielectric ceramic compositions and they were inspected for characteristic

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properties. The results thus obtained are summarized in Table 9.

TABLE 8

5		COMPOSITION OF DIELECTRIC CERAMIC								CALCINATION	
		BaO	TiO ₂	Nd ₂ O ₃	Sm ₂ O ₃	Bi ₂ O ₃	GLASS	KIND OF	GeO ₂	Li ₂ O	TEMPERATURE
		x	y	z	t	w	POWDER	GLASS	wt%	wt%	°C
							wt%				
10	EXAMPLE										
	62	0.13	0.69	0.16	0	0.02	2	A	3	0.4	945
	63	0.17	0.66	0.11	0.04	0.02	7	A	3	0.2	920
	64	0.17	0.66	0.10	0.04	0.03	10	A	3	0.2	890
	65	0.18	0.66	0.11	0.04	0.01	15	A	3	0.2	880
15	66	0.15	0.67	0.10	0.06	0.02	20	A	2	0.4	860
	67	0.17	0.66	0.12	0.03	0.02	5	B	5	0.4	960
	68	0.17	0.66	0.10	0.06	0.01	10	B	3	0.8	920
	69	0.16	0.64	0.16	0.02	0.02	15	B	3	0.4	900
20	70	0.13	0.69	0.16	0	0.02	7	A	3	0.4	920
	71	0.12	0.70	0.14	0.02	0.02	7	A	3	0.4	920
	72	0.13	0.69	0.11	0.05	0.02	7	A	3	0.4	920
	73	0.14	0.70	0.04	0.10	0.02	10	A	5	0.2	920
	74	0.17	0.66	0.16	0	0.01	10	A	5	0.2	900
25	75	0.16	0.66	0.16	0	0.02	10	A	7	0.2	915
	76	0.16	0.66	0.16	0	0.02	10	A	10	0.2	920
	77	0.15	0.65	0.17	0.01	0.02	7	A	3	0.2	925
	78	0.15	0.65	0.17	0.01	0.02	7	A	3	0.4	905
	79	0.15	0.65	0.17	0.01	0.02	7	A	3	0.6	900
30	80	0.15	0.65	0.17	0.01	0.02	7	A	3	0.8	875
	81	0.14	0.67	0.17	0	0.02	10	A	5	0.4	860
	82	0.14	0.67	0.17	0	0.02	15	A	3	0.4	845
35	COMPARATIVE										
	EXAMPLE										
	48	0.05	0.75	0.18	0.01	0.01	10	A	5	0.2	935
	49	0.30	0.57	0.10	0.02	0.01	10	A	3	0.2	920
	50	0.08	0.86	0.04	0.01	0.01	15	A	3	0.4	880
40	51	0.14	0.45	0.38	0.01	0.02	9	A	2	0.6	890
	52	0.11	0.56	0.31	0.01	0.01	10	A	2	0.8	885
	53	0.10	0.87	0	0.01	0.02	10	A	2	0.4	905
	54	0.13	0.55	0.01	0.30	0.01	5	A	3	0.4	915
45	55	0.18	0.67	0.14	0.01	0	2	A	2	1.5	955
	56	0.20	0.64	0.05	0.01	0.1	7	A	3	0.4	910
	57	0.14	0.69	0.13	0.02	0.02	0	-	0	0	1400
	58	0.15	0.67	0.11	0.06	0.01	30	A	2	0.4	850
	59	0.15	0.65	0.16	0.02	0.02	30	B	3	0.4	820
50	60	0.16	0.66	0.16	0	0.02	20	A	0	0.2	1130
	61	0.14	0.70	0.13	0.02	0.01	10	A	15	0.4	835
	62	0.16	0.65	0.17	0.01	0.01	7	A	3	6.0	855
	63	0.16	0.67	0.10	0.06	0.01	10	B	3	0	950

TABLE 9

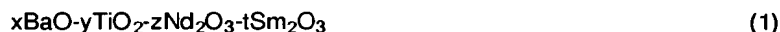
ELECTRIC CHARACTERISTICS				
	ϵ_r	Q	τ_r	
			ppm/°C	
EXAMPLE				
62	76.0	1450	35	
63	78.0	1160	18	
64	73.0	1110	5	
65	71.0	900	4	
66	70.0	640	2	
67	79.0	1050	35	
68	73.0	760	29	
69	81.0	1200	73	
70	75.0	1250	29	
71	74.0	1050	15	
72	73.0	990	-5	
73	64.0	730	-18	
74	71.0	1100	30	
75	67.0	1050	25	
76	62.0	950	19	
77	74.0	1080	30	
78	76.0	1020	40	
79	79.0	1050	43	
80	75.0	800	50	
81	68.0	1100	-22	
82	70.0	790	-22	
COMPARATIVE				
EXAMPLE				
48	49.0	170	13	
49	NO RESONANCE			
50	69.0	300	150	
51	43.0	190	72	
52	47.0	90	30	
53	66.0	350	105	
54	47.0	310	-5	
55	60.0	390	47	
56	47.0	180	-15	
57	88.0	2770	15	
58	35.0	240	23	
59	29.0	170	29	
60	97.0	120	75	
61	45.0	230	-22	
62	NO RESONANCE			
63	71.0	650	-10	

As has been discussed above in detail, the dielectric ceramic composition of the present invention exhibits excellent characteristic properties in that it has a large specific dielectric constant ϵ_r , a large unloaded Q and a small temperature

coefficient of the resonance frequency and the composition is advantageous in that it can be sintered at a low temperature and that it can easily be laminated together with, for instance, an Ag, Ag-Pd or Cu internal electrode.

Claims

1. A dielectric ceramic composition mainly comprising a major component which comprises barium, titanium, neodymium, samarium and oxygen and is represented by the following compositional formula:



(wherein $0.1 \leq x \leq 0.2$; $0.5 \leq y \leq 0.8$; $0.01 \leq z \leq 0.2$; $0 \leq t \leq 0.2$, provided that $x+y+z+t = 1$); and

a minor component mainly comprising glass powder, which mainly comprises PbO , ZnO and B_2O_3 , and GeO_2 , and wherein

the content (a) (% by weight) of the glass powder falls within the range of $1 \leq a \leq 25$ and the content (b) (% by weight) of GeO_2 falls within the range of $0.5 \leq b \leq 10$, on the basis of the weight of the major component.

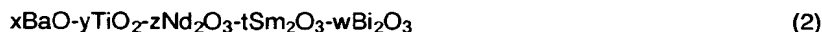
2. The dielectric ceramic composition of claim 1 which further comprises Li_2O as a minor component and the content (c) (% by weight) of Li_2O falls within the range of $0.04 \leq c \leq 4$ on the basis of the weight of the major component.

3. The dielectric ceramic composition of claim 1 or 2 which further comprises at least one member selected from the group consisting of Nb_2O_5 , MnO , Al_2O_3 and ZnO .

4. The dielectric ceramic composition of claim 1, 2 or 3 wherein the content of PbO , ZnO and B_2O_3 are $5 \leq \text{PbO} \leq 90$, $5 \leq \text{B}_2\text{O}_3 \leq 60$ and $0 < \text{ZnO} \leq 65$ (% by weight).

5. The dielectric ceramic composition of claim 4 wherein the softening point of the glass powder is about 100°C to about 500°C .

6. A dielectric ceramic composition mainly comprising a major component which comprises barium, titanium, neodymium, samarium, bismuth and oxygen and is represented by the following compositional formula:



(wherein $0.1 \leq x \leq 0.2$; $0.5 \leq y \leq 0.8$; $0.01 \leq z \leq 0.2$; $0.01 \leq t \leq 0.2$; $0.005 \leq w \leq 0.05$, provided that $x+y+z+t+w = 1$); and

a minor component mainly comprising glass powder, which mainly comprises PbO , ZnO and B_2O_3 , and GeO_2 , and wherein

the content (a) (% by weight) of the glass powder falls within the range of $1 \leq a \leq 25$ and the content (b) (% by weight) of GeO_2 falls within the range of $0.5 \leq b \leq 10$, on the basis of the weight of the major component.

7. The dielectric ceramic composition of claim 6 which further comprises Li_2O as another minor component and the content (c) (% by weight) of Li_2O falls within the range of $0.04 \leq c \leq 4$ on the basis of the weight of the major component.

8. The dielectric ceramic composition of claim 6 or 7 which further comprises at least one member selected from the group consisting of Nb_2O_5 , MnO , Al_2O_3 and ZnO .

9. The dielectric ceramic composition of claim 6, 7 or 8 wherein the content of PbO , ZnO and B_2O_3 are $5 \leq \text{PbO} \leq 90$, $5 \leq \text{B}_2\text{O}_3 \leq 60$, and $0 < \text{ZnO} \leq 65$ (% by weight).

10. The dielectric ceramic composition of claim 9 wherein the softening point of the glass powder is about 100°C to about 500°C .

11. A dielectric device such as a dielectric resonator and a dielectric filter, comprising a dielectric ceramic composition according to any one of claims 1 to 10.



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EUROPEAN SEARCH REPORT

Application Number
EP 95 11 3625

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	DATABASE WPI Week 8215 Derwent Publications Ltd., London, GB; AN 82-29982E & JP-A-57 040 806 (TDK) , 6 March 1982 * abstract *	1,11	C04B35/468 H01B3/12 H01G4/12
A	DATABASE WPI Week 9207 Derwent Publications Ltd., London, GB; AN 92-52757 & JP-A-03 295 854 (SUMITOMO METAL) , 26 December 1991 * abstract *	1,4,6,9,11	
Y	EP-A-0 551 100 (E.I.DU PONT DE NEMOURS) * page 3, line 24 - page 4, line 37; claims *	6,8	
A	* the whole document *	1,4,5,9-11	
Y	EP-A-0 473 347 (NGK INSULATORS) * abstract; claims *	6,8	TECHNICAL FIELDS SEARCHED (Int.Cl.6) C04B H01B H01G
A	* the whole document *	1,3,11	
A	DATABASE WPI Week 9404 Derwent Publications Ltd., London, GB; AN 94-29075 & JP-A-05 334 914 (SUMIZOMO METAL) * abstract *	1,4-6,9-11	
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 21 December 1995	Examiner Harbron, J
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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Application Number
EP 95 11 3625

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	DATABASE WPI Week 9416 Derwent Publications Ltd., London, GB; AN 94-129441 & JP-A-06 076 627 (TAIYO YUDEN) , 18 March 1994 * abstract *	1,2,6,7	
A	GB-A-2 068 931 (CENTRALAB INC.)		
A	EP-A-0 412 440 (OKI ELECTRIC INDUSTRY)		
A	DATABASE WPI Week 8943 Derwent Publications Ltd., London, GB; AN 89-314692 & JP-A-01 234 358 (MATSUSHITA)		
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 21 December 1995	Examiner Harbron, J
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application I : document cited for other reasons</p> <p>& : member of the same patent family, corresponding document</p>			

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